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# Underwater acoustic absorption of air-saturated open-celled silicon carbide foam

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## HIGHLIGHTS

- Silicon carbide foam was prepared by MRI process.
- We study the underwater acoustic absorption capacity of SiC foams.
- Decreasing the pore size will improve the acoustic absorption capacity.
- Increasing sample thickness will improve the acoustic absorption capacity.
- JCA model cannot be applied to the current model studied.

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## ABSTRACT

Silicon carbide (SiC) foam prepared by polymer pyrolysis combined with molten silicon reactive infiltration (MRI) process was experimentally studied for the first time regarding its underwater acoustic absorption coefficient ($\alpha$) mainly over low and middle frequency range (200–4000 Hz). The relationship between $\alpha$ and the pore structure of SiC foam including pore size ($d$) and foam thickness ($t$) was studied. The results indicated that $\alpha$ increased with the decrease of pore size from 3 to 1 mm in most frequencies measured. $\alpha$ also increased with sample thickness at both low and medium frequency, but in general it was more sensitive to pore size than to sample thickness. The existing models built for air-filled porous material under atmospheric circumstance were not valid to describe the underwater acoustic absorption behavior of SiC foam materials.



## 1. Introduction

An attractive combination of sound absorption together with mechanical stiffness and strength at low weight can be achieved through the introduction of appropriately processed and designed materials such as open-celled metal foams or ceramic foams. But till now most of the existing investigations on sound propagation in porous materials are confined to air-saturated and air-enclosed porous materials [1–11]. Porous material has been considered as an equivalent fluid with equivalent density and bulk modulus when its solid skeleton is treated as rigid. Under this hypothesis many models serving for investigation of sound propagation in porous media are developed. Based on a large number of measurements, empirical formulas [12–15] and semi empirical models [16] have been well established for air-saturated porous material. Also, there are many theoretical models involving various physical parameters of the porous media developed [17–21]. But still they only intend for the air-saturated porous material put under atmospheric circumstance. When it comes to the underwater acoustic absorption, theoretically, because of the severe impedance mismatch between the porous material and water, it is difficult for the incident sound wave to enter the porous material and most of the incident wave will be reflected, which results in poor underwater absorption performance. The poor acoustic absorption capacity caused by impedance mismatch will be worsened in low frequency region. Topics dealing with underwater acoustic absorption performance of porous materials have been studied only by a few researchers and the results are almost focused only on metal foams. Cheng et al. investigated the underwater sound-absorbing qualities of porous aluminum and concluded that absorption was best with a porosity range of 0.75–0.8 [22]. But the acoustic absorbing capacity in low or middle frequency region was not mentioned. Wang [23] established an optimized model, in which a thin porous sample saturated by viscosity liquid showed effective underwater acoustic absorbing capacity. Compared to metal foams, ceramic foams have advantages on its better stiffness and corrosion resistance.

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Therefore they are more prosperous in catering for severing underwater conditions. However, acoustic properties of SiC foam have been very poorly investigated so far and to our best knowledge no literatures have been dedicated to its underwater acoustic absorption performance. There is especially lack of knowledge about the open-celled foams to serve for underwater acoustic absorption over low and middle frequency band. In addition, an ambiguity whether the existing theoretical models can be directly applied to foams enclosed by water or not should be clarified.

In this work, the underwater acoustic properties of polymer pyrolysis and MRI-derived SiC foams have been investigated for the first time. Finite element method (FEM) implementation and experimental tests are described, and the results are compared to that of the empirical or theoretical acoustic methods. We will show that these foams, especially the one with 1 mm pores and 90 mm thickness, are good underwater acoustic absorbent even in low and mid frequency band. However, the empirical or theoretical models concerned with air environment cannot be applied to the underwater environment.

## 2. Experimental method

### 2.1. Foam preparation

The SiC foam samples were produced by polymer pyrolysis combined with MRI method at Institute of Metal Research (IMR), Chinese Academy of Sciences (CAS). Brief description of the method can be found elsewhere [24]. The detailed structural information and typical pore morphology of the prepared SiC foams are shown in Table 1 and Fig. 1, respectively. Fig. 1a shows a section of one of the test samples with 80% porosity and 1 mm pore size. As can be clearly seen from Fig. 1b, millimeter scaled and tetrakaidecahedron-shaped [25] pores are periodically arrayed or evenly distributed to form three-dimensional (3D) reticulated macrostructure of SiC foam matrix with very few blind or closed pores. Moreover, the microscopic configuration of the SiC foam used in this study is very different from that of conventional metallic porous materials as there are many sub-pores connected each other to form micro-channels with size of some microns distributed throughout the foam skeleton (see Fig. 1d). According to the works of Cheng et al. [22], the optimum porosity for best underwater sound absorption performance falls in the range of 75–80%. Therefore five types of specimens were prepared all having the same porosity of about 80% in this study. Three of the prepared samples had the same thickness of 90 mm but different mean pore sizes of 3, 2 and 1 mm, and another two had the same pore size of 1 mm but different thicknesses of 30 and 60 mm, respectively. All the tested samples were prepared as a circular cylinder of 118 mm in diameter.

**Table 1**
Structural parameters of SiC foam samples.

| Sample number | Porosity (%) | Pore size (mm) | Sample thickness (mm) |
|---|---|---|---|
| A | 80 | 1 | 30 |
| B | 80 | 1 | 60 |
| C | 80 | 1 | 90 |
| D | 80 | 2 | 90 |
| E | 80 | 3 | 90 |

### 2.2. Acoustical experiments and analysis

A transfer function method was used in measuring the normal incident underwater acoustic absorption coefficient of the porous SiC samples. The principals followed by the measurements were the same to that in air condition as can be found in many literatures and ISO standards [3,10]. The differences were the impedance tube used in our experiment was filled with water and had different length and inner diameters to generate necessary frequency band of incident sound signal. All the samples were packed carefully with polyurethane films (PUF) to prevent water

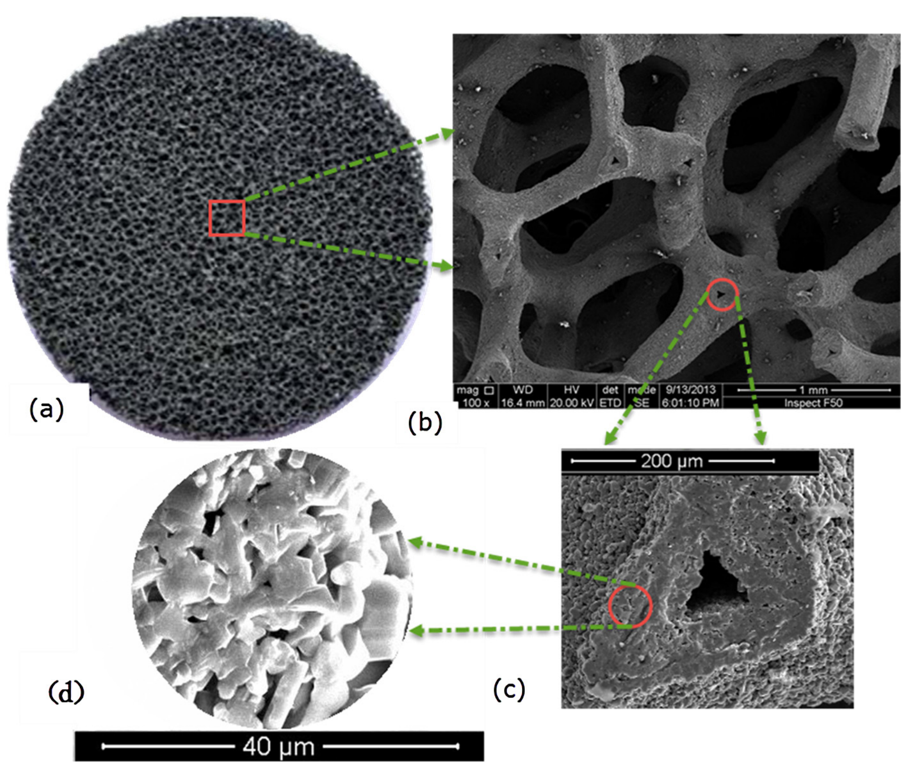


**Fig. 1.** Photograph of a section of SiC foam sample (a), scanning electron microscope photographs of the cell structure (b), triangular cross section of hollow skeleton (c), and micro-pores throughout the strut of foam skeleton (d).